POWER FLUIDICS - THE ROBUST ALTERNATIVE FOR TANK WASTE MIXING AND RETRIEVAL

P. Murray
AEA Technology Engineering Services

M. D. Biggs
BNFL Inc.

ABSTRACT

Power Fluidics is the generic name for a range of maintenance free nuclear equipment built around the common principle of using one medium, most commonly air, to move fluids. Power Fluidics equipment was developed through collaboration between British Nuclear Fuels plc (BNFL) and the United Kingdom Atomic Energy Authority (UKAEA) to work in highly radioactive environments with little or no maintenance requirements. This development was driven by the need for low maintenance, high availability fluid mixing and transfer devices that are durable for 30 year plant operations. Nuclear applications of Power Fluidic devices include vessel agitation, transfer of process liquids and sludge, tank heel emptying, and tank Deactivation and Decommissioning (D&D).

Significant cost and safety benefits are achieved by using Power Fluidic devices in place of their mechanical equivalents. Fluidic devices generally have no moving parts in contact with process fluid and therefore require no maintenance of contaminated equipment. Power Fluidic devices therefore eliminate replacement costs of worn out components, significantly reduce routine maintenance, reduce secondary waste, reduce worker dose uptake, increase equipment availability and, significantly reduce plant lifetime costs.

Fluidic Tank Waste Mixing and Retrieval Power Fluidics Equipment has been deployed for retrieval of waste from tanks and silos across the United States Department of Energy (US DOE) complex, with an inventory ranging up to 380 m^3. Systems have also been developed to retrieve waste from facilities with storage capacities up to 3800 m^3. This technology has demonstrated advantages over "past practice sluicing" and other retrieval technologies. Fluidic Tank Waste Mixing and Retrieval Equipment has been successfully used to remove waste in tanks at many sites across the DOE complex including, Oak Ridge National Laboratory (ORNL), Savannah River Site, Idaho National Engineering Laboratory, Mound and Los Alamos.

This paper describes the current successes of AEA Technology and BNFL Inc. in the US deployment of Power Fluidics, and describes planned deployment for mixing and retrieval of miscellaneous radioactive stored sludge from historical storage facilities.

This paper will appeal to companies with radioactive fluid or sludge mixing and retrieval requirements from tanks and silos.

INTRODUCTION

AEA Technology is formerly part of the United Kingdom Atomic Energy Authority (UKAEA), and offer solutions based on know-how built up over 40 years of leading edge science and engineering in the nuclear industry. Today, the business focuses on five key areas: technology-based products, specialized science, environmental management, improving the efficiency of industrial plant, and risk assessment and safety management. In each area they offer services, products, consultancy, software and technology transfer.

BNFL Inc. is an American environmental services company whose expertise is providing technical solutions to clean up nuclear waste. They are focused on providing innovative solutions for the nation's most difficult environmental and nuclear challenges. BNFL Inc. is a member of the British Nuclear Fuels group of companies which provides fuel manufacture and uranium procurement, as well as recycling used fuel, transporting radioactive materials, engineering, waste management and decommissioning services.

Power Fluidics equipment was developed through collaboration between British Nuclear Fuels plc (BNFL) and UKAEA to work in highly radioactive environments with little or no maintenance requirements. This development was driven by the need for low maintenance, high availability fluid mixing and transfer devices that are durable for 30 year plant operations. The equipment was therefore developed to meet the principle of "lifetime" costs for plant operation. Nuclear applications of Power Fluidic devices include vessel agitation, transfer of process liquids and sludge, tank heel emptying, and tank Deactivation and Decommissioning (D&D).

Power Fluidics is the generic name for a range of maintenance free nuclear equipment built around the common principle of using one medium, most commonly air, to move fluids. Fluidic devices generally have no moving parts in contact with process fluid and therefore require no maintenance of contaminated equipment. Significant cost and safety benefits are achieved by using Power Fluidic devices in place of their mechanical equivalents by:

- Eliminating replacement costs of worn out components.
- Eliminating much routine maintenance and associated radiation exposure.
- Reducing secondary waste due to worn out components and maintenance work.
- Reducing health physics and safety paperwork associated with the maintenance.
- Increasing plant productivity due to reduced maintenance schedules.

Fluidic Tank Waste Mixing and Retrieval Equipment has been successfully used to remove the bulk of the waste from the following tanks: Oak Ridge National Laboratory (ORNL) BVEST Tanks W21, W22, W23, C1, C2, Capacity Increase Tanks at Oak Ridge, and Pump Tank 1 at Savannah River, Hot Waste Tanks at Idaho National Engineering Laboratory, and the Effluent Tank at Los Alamos. In each case, the projects were performed below the baseline costs and ahead of the baseline schedules.

The final point of a tank retrieval project is completely subjective. Removing all the contents of a tank would be extremely time consuming and expensive and therefore in many cases, unrealistic. Is 90% recovery demanded and if so 90% of what. It is often as difficult to determine how much waste was in the tank to begin with as to determine how much waste was left. Once again the old argument of "how clean is clean?" resurfaces.

This paper describes the operating principles of Power Fluidic devices, the principal components in the mobile fluidic system, examples of successful deployment of this system in the US nuclear market, and planned deployment for the recovery of High Level Waste (HLW) sludges from storage silos.

MOBILE FLUIDIC MIXING AND RETRIEVAL SYSTEM OPERATING PRINCIPLES

The mobile Fluidic Tank recovery system consists of a series of modular skids capable of being moved by forklift truck into a convenient area adjacent to a tank or silo. A purpose built nozzle is installed into the tank and double contained flexible hose used to attach the nozzle to the charge vessel skid. Various types of nozzle can be deployed based upon the tank configuration. Several designs of nozzle can be installed at the same time into a legacy waste tank to meet different requirements. These are:

- Fixed: will mix the tank without the need to move in any orientation.
- Fixed Rotating: rigid nozzle capable of 360' rotation and some vertical movement.
- Directional Nozzle: capable of being aimed at individual points within the tank.

It is assumed that the legacy waste tank contains sludge and that a layer of free water or supernate is present above the sludge bed. If no free liquid is available then some fresh water or recycled supernate from an adjacent tank may need to be added to the tank to allow the recovery of the waste to be achieved.

The pulse mobile system mobilizes waste via a three phase mixing process:

- Suction phase
- Drive phase
- Vent phase

During the suction phase the free liquid or supernate in the tank is sucked out through the nozzle into the charge vessel, entraining a small amount of sludge. Once the charge vessel is full, the liquid is forced back into the tank using compressed air creating a mixing jet that mobilizes the residual sludge in the tank, as shown in Figure 1.

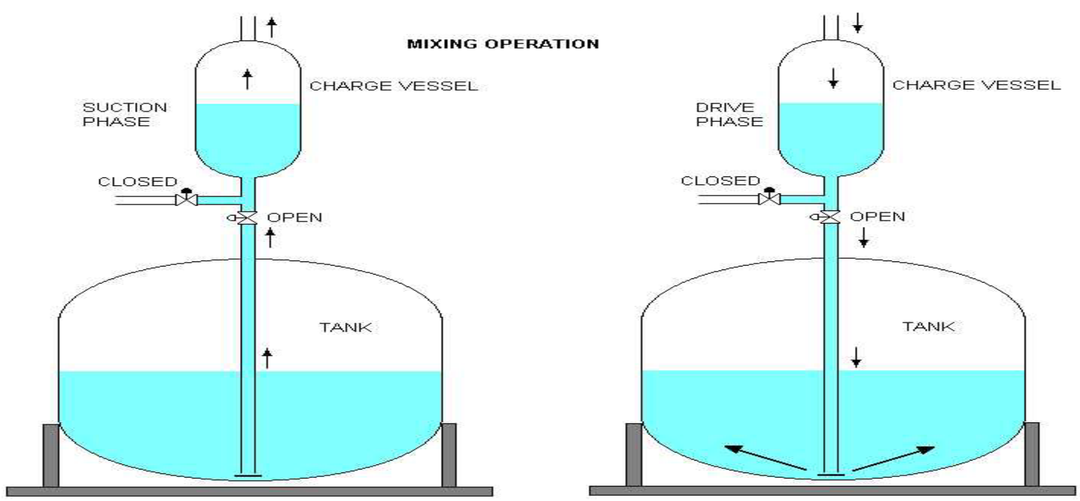

Fig. 1 Fluidic mixing operating cycles

This process of filling the charge vessel and discharging it back into the tank is repeated until all the free sludge in the tank has been mobilized into the bulk liquid. At this point the capability exists to draw a mixed representative sample of the waste in the tank for analysis. Following analysis the waste can be re-mixed and transferred using the charge vessel or a dedicated transfer pump, as shown in Figure 2.

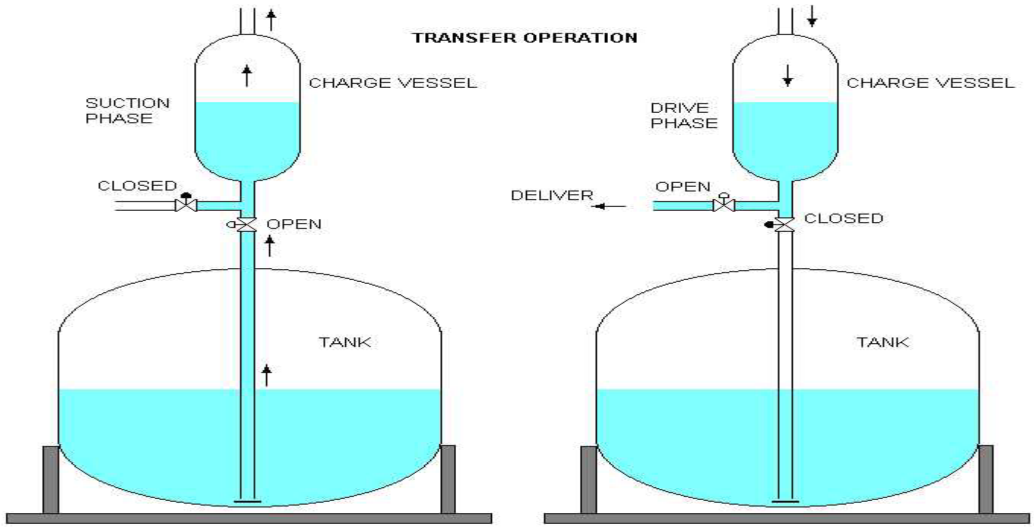

Fig. 2 Transfer system operating cycles

MOBILE FLUIDIC SYSTEM PRINCIPAL COMPONENTS

A mobile fluidic system will typically consist of the following modules, or skids:

- Charge Vessel Skid
- Control Skid
- Off-Gas Skid
- In-Tank Equipment

With the exception of the in-tank equipment, each of these modules are usually located above ground adjacent to the tank, connected by the requisite electrical and instrument cables, and flexible hoses for air, water, and slurry/sludge. The system is controlled using a control system housed in a mobile weatherproof 'hut'. Ventilated air from the system will be discharged through a mobile HEPA filter on the Off-Gas Skid.

The in-tank equipment includes the pulse tube(s) and nozzle(s), and will comprise one or more purpose-designed modules deployed into the tank or silo. Wherever possible these modules are designed to be deployed through existing penetrations into the tank or silo to reduce the intrusiveness of the system and provide associated cost and safety benefits.

Charge Vessel Skid

The charge vessel skid is typically 2.74m wide x 4.57m long x 4.27m high, and consists of:

- The Charge Vessel: This is a U stamped pressure vessel. The sludge is sucked up into this vessel before being discharged to either the tank or the discharge line.
- The Jet Pump Pair: This is used to generate either a vacuum or a pressure within the charge vessel dependent upon the current phase in the process.
- The Demister: This is used to eliminate airborne particulates from being carried over into the off gas system.
- Process Valves: These are the automated valves providing connections to the sludge tank, discharge line and supply line dependent upon the operating regime of the mixer system.
- Hydraulic Power Unit: to provide the motive power to the wall wash nozzles

All air lines and valve bodies may be electrically trace-heated for cold weather operation. The Jet Pump Pair is fitted with a dedicated heater. Level detection devices are fitted to the charge vessel and to the demister to indicate to the PRESCON™ controller that these vessels are at their high limit.

Control Skid

The control skid is typically 3.67m long x 2.44m wide x 2.29m high, and contains the system control panel, the jet pump drive and suction valves and pipework, and the wash water valves and pipework.

The control skid is linked to the charge vessel skid by flexible hoses and an electrical services umbilical cord.

The connection points for Air, Water and Electricity are located on the exterior of the control hut.

The Control System

The system is comprised of both computer-based and conventional electrical and instrument control equipment that provide the necessary sequencing, monitoring, control and power for the valve, jet pump and charge vessel plants.

Sequence control and monitoring of all process equipment on the valve and charge vessel skids is performed from the PRESCON™ controller.

Off-Gas Skid

During the vent phase of the pulsejet mixing system, gas is vented from the charge vessels via the jet pumps. As this off-gas will have been in contact with contaminated liquor in the charge vessels, a protective off-gas system is provided. The off-gas system is designed for an intermittent exhaust off-gas flow rate from the jet pumps; typically, in the range 0.47 m^3/sec (peak), 0.12 m^3/sec (average), during pump operation.

The off-gas system has two stages of HEPA filtration to provide primary and secondary protection, with each stage having a maximum penetration of 0.05%. The HEPA filters are a 'bag-out' design. A belt-driven centrifugal fan with duty and standby motors, sufficient to overcome the ductwork, equipment and filter pressure drops, provides the airflow through the system.

Filtered make-up air is added to the off-gas flow via a dedicated in-bleed system prior to the primary HEPA filter to create a more constant flow rate through the fan. The air in-bleed system comprises an 80% arrestance panel filter, a 95% arrestance bag filter, a 99.95% arrestance back-flow protection HEPA filter and a flow-regulating valve.

The off-gas is heated prior to HEPA filtration by an electric heater to provide protection to the HEPA filters against a saturated airflow (by reducing the percentage relative humidity to < 70%). All HEPA filters are provided with sufficient upstream and downstream sampling points to comply with Dioctyl Phthalate (DOP) integrity test requirements.

Finally, to provide adequate dispersal of the residual contamination within the filtered air, the discharge to atmosphere is via an exhaust stack. A typical Off-Gas Skid is 7.32m long x 2.29m wide x 4.57m tall (including stack which is removable for transport)

In-Tank Equipment

The in-tank equipment typically comprises the suction/mobilization nozzle (pulse tube) and, if required, wash nozzle and camera. This equipment is arranged in the form of a mast that is deployed into the tank and supported by an interface plate.

The wash nozzles are typically hydraulically-actuated, electrically-controlled units that are manipulated from a cabinet located in the control skid. The video cameras are connected to a monitor in the control skid. The in-tank equipment must be deployed through a suitable penetration into the tank. Any number of these units may be deployed into the tank, dependent upon the tank size, configuration, and availability of access.

EXAMPLES OF DEPLOYMENT IN THE US DOE COMPLEX

The following describes several recent successful applications of fluidic technology to mobilization and retrieval of radioactive waste from existing tanks or silos.

Mound WD Complex, Ohio USA, 2002

Designed and constructed in 1948, building WD at Mound was the treatment facility for low specific activity (LSA) radioactive wastes generated by process activities. Active and inactive processes housed within the WD facility included alpha and beta wastewater treatment, laboratory and bench-scale research, LSA waste drum repackaging, a glass melter furnace and a packed bed reactor. One of the challenges the site is facing with deactivating and decommissioning the facilities is waste retrieval and eventual treatment of waste from the 36 waste tanks and sumps in the WD complex containing various types of wastes and varying in size from 3.8 m^3 - 150 m^3.

In compliance with the D&D plan for the facility, the contents from the WD tanks will be retrieved and stored until a treatment process is identified. The walls of the tanks will then be washed and the subsequent contents will be retrieved and transported for treatment. Finally, the site will remove the tanks as part of the Facility Decommissioning Project.

Through a contract with the US DOE Office of Science and Technology, AEA Technology was assigned the task of deploying a mobile, skid-mounted tank waste retrieval system to Mound to retrieve the waste from two of the WD complex storage tanks. The system, a Small Tank Mixer (STM), had been previously deployed at Oak Ridge and was then transferred to Mound in 2001.

When the initial phase of the waste retrieval was completed in 2001, it was determined that the rotational nozzle was very successful in removing the bulk waste from the tanks, but was not effective in removing the crusted carbon sludge from the sidewalls of the tanks.

Therefore, in 2002 AEA Technology modified the system to include the capability to wash the inside of the tanks after the waste was retrieved. A remote controlled articulating nozzle was designed to rotate 360º and travel up and down, vertically, in the tank.

The modified system was able to remove the crust from the tank walls and provided the site with a single system to retrieve the waste and also clean the inside of the tanks, in compliance with D&D milestones.

Tech Area 50 (TA-50) Sludge Tank, Los Alamos National Laboratory, New Mexico, USA, 2003

The US Department of Energy has a large inventory of storage tanks with unique geometry's that contain radioactively contaminated wastes. The TA-50 facility at LANL has a number of such tanks. The properties, quantities and disposition of the waste are unknown; however, it is believed that these tanks contain residual waste that may also be encrusted onto the walls, and could contain solid debris. The presence of this waste is an impediment to safe and efficient site operations and a method was required to mobilize, mix and retrieve the waste from these tanks.

During 2001, AEA Technology completed design and functional testing of a directional nozzle system suitable for mobilizing and recovering sludge from the TA-50 facility Sludge and Influent Process Tanks prior to their return to service. During 2002, AEA Technology supplied a skid-mounted tank waste mobilization and retrieval system to the TA-50 facility at LANL to start mobilizing and retrieving the legacy waste from the tanks at this facility. Active operations commenced in October 2002.

Using a specialized Fluidic Pulse Jet Mixing System enabled mobilization and retrieval of the encrusted sludge from within the tanks. Deployment enabled efficient retrieval while minimizing radioactive exposure, and facilitating an accelerated schedule for D&D at LANL.

FUTURE DEPLOYMENT

Power Fluidics is intended to be deployed for the recovery of sludge generated by corroded nuclear fuel swarf and fuel debris, currently stored in a silo storage facility. Throughout the course of 20 years of operation, the silos have been filled with swarf and miscellaneous Beta-Gamma waste (MBGW). The swarf is believed to have corroded to a clay-like consistency. The MBGW includes a wide range of items, such as wire rope, cables, PPE, plastic, pumps, and valves. Hydrogen generation must be managed, and measures taken to deal with quantities of hydrogen, which could be trapped within the sludge, or held, in the debris buried in the sludge.

Each of the silos is approximately 6.4m x 6.4m x 18.3m deep, and of approximately $500m^3$ capacity. Waste is stored underwater in the silos with 1-2m of water over the waste. There is a 0.3m deep gravel bed at the base of each silo put in place to act as a cushion to prevent damage to cell from debris dropped in. Each silo is accessed through a 1.8m square opening centrally located at the top closed by a large removable concrete plug. The silos mainly contain sludge, though large items of MBGW should also be expected.

Description Of Sludge Retrieval Equipment

The system proposed for retrieving and emptying the silos will be a skid mounted modular system capable of being deployed to mobilize and transfer waste from a single silo. On completion of operations, it is expected to be moved to the next silo to recover the waste.

With the exception of the pulse tube and nozzle assembly, each of the modules will be located in position on the floor above the silos, connected by the requisite electrical and instrument cables, and flexible hoses for air, water, and slurry/sludge. The various components of the system are shown schematically in Figure 3.

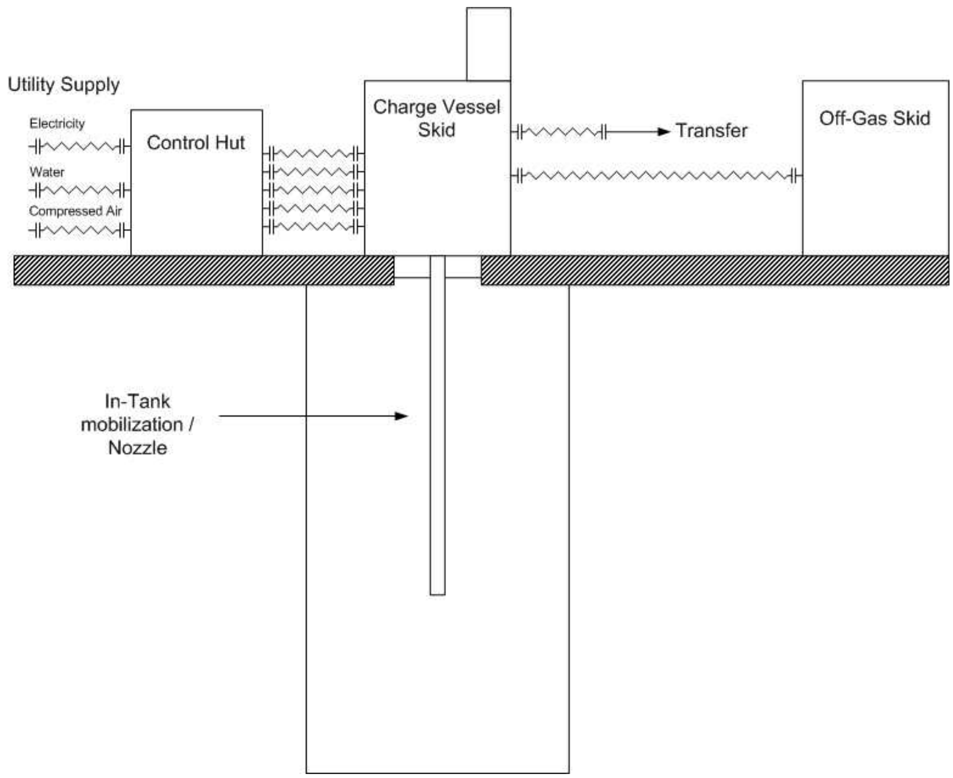

Fig. 3 Schematic of equipment modules (not to scale)

Nozzle Design

Due to the restricted space available above the silos the nozzle has to be installed into the silos utilizing a flexible hose to allow the full vertical travel, and a series of rigid sections added to give the required rigidity to the system.

Flexible hose could be deployed into the silo using an air driven hose reel. This hose management system could easily be deployed inside the shielded container housing the charge vessel.

To give the flexible hose the rigidity required, the end of the hose would be attached to a simple structural support mast. The overall height of the mast would be limited by the overhead clearance of approximately 6m making it necessary to use several sections of mast to cover the entire depth of the silo. New lengths of support mast would be progressively installed as the nozzle is lowered (it is expected that in total this operation will only occur two or three times).

Since the main retrieval hose is not broken to add in new sections, this design of nozzle has the advantage of increased safety and reduced potential for exposure to operators. The only added complication compared to a normal Fluidic Recovery System is the use of a hose management reel to deploy the nozzle. The precedent for the use of hose management systems has been set by the operations at the Gunite Tanks at Oak Ridge. Lessons learned from these site operations will be collated during the next phase of the project and incorporated into the design of the system for the silos.

The nozzle design for this system will be capable of 360 degrees of rotation and of vertical movement within the silo. Due to the proposed retrieval strategy, and the presence of debris in the silo, this additional degree of freedom will be very beneficial in the recovery of the waste. The pulse tube and nozzle assembly will be located in place on the silo opening using an interface plate that will mate up with the silo opening. The pulse tube and nozzle assembly will be attached to the plate on a rotational bearing that will allow for lateral rotation of the pulse tube and nozzle assembly. This lateral rotation of the pulse tube and nozzle assembly will allow the nozzle to prescribe a predetermined circle in the silo. This design has the added advantage that the nozzle is not centrally located in the opening to the silo providing potential for deployment of a recovery mechanism to remove solid debris, as it is uncovered during the sludge recovery. Figure 4 shows the general equipment arrangement within the silo.

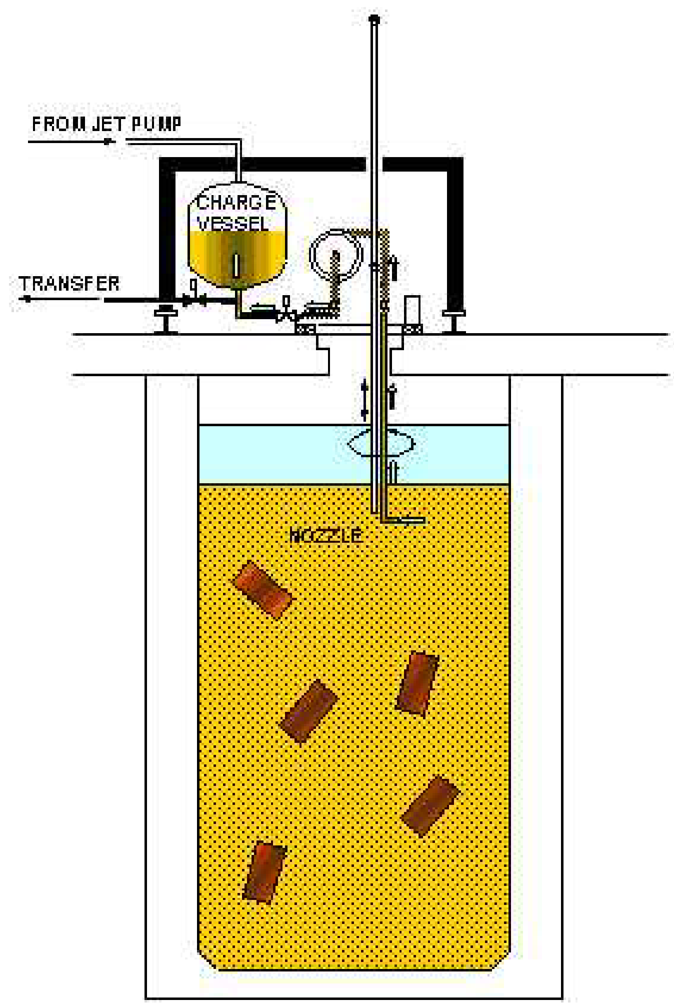

Fig. 4 Silo Sludge Retrieval System

Proposed Retrieval Strategy

It is initially proposed to remove any large floating debris from the silo by a mechanical grab prior to deployment of the Power Fluidics retrieval system. Once these large pieces of debris have been removed the initial waste recovery will commence.

It is not practical or reasonable to try and homogenize the contents of the silo prior to recovery. A more pragmatic and safe way is to treat the waste in the silo as a series of discreet sections, recovering each section in turn, exposing any large debris, removing the debris and moving onto the next section of sludge.

With this philosophy in mind, the nozzle will be lowered until it is submerged in the sludge bed to some predetermined depth. This depth will be dictated by experience on the silos and the debris that is encountered.

Once the nozzle is submerged in the sludge the waste will be sucked into the charge vessel. Once the charge vessel is full, the waste will be discharged into a High Integrity Container (HIC) or pipeline for transfer to the treatment site.

The nozzle will then be moved a few degrees horizontally, utilizing the slewing. The process of sucking waste into the charge vessel and transferring to the HIC will be repeated. The nozzle will continue to be moved using the slewing ring, until the nozzle has achieved 360 degree movement around the silo, effectively excavating a trench in the waste.

This initial recovery method has several distinct advantages:

1. Visual control of the system and the recovery is maintained.
    - Improved safety
    - Reduced risk of disturbing hydrogen containers
    - Identification of MBGW
2. A large volume of the sludge can be recovered. Resulting in an annular trench within the waste.
    - Allows for visual examination through vertical segments of the sludge bed
    - Recovery should result in relatively high solids loading in recovered waste.

Leveling the Sludge Bed Surface

The process described in the proceeding sections can be utilized to remove the waste in a controlled manner to reduce risk of unexpected release of hydrogen or an unexpected encounter with MBGW. Once the waste "annulus" has been formed and assuming no unacceptably large debris items have been encountered, the mixing system can be used to level the sludge bed by sucking sludge/supernate into the charge vessel and discharging it to fall under gravity back into the silo. The nozzle will be rotated about its axis during this step of the sludge recovery process.

After a predetermined period, the mixing will be stopped and the sludge allowed to settle. Following the settling of the sludge the "annular" recovery process would recommence, recovering more sludge from progressive vertical segments of the silo. This process would continue until the majority of sludge was recovered from the vertical segments of the silo. The nozzle mast would then be lowered and the process repeated.

MOBILE FLUIDIC SYSTEMS - SUMMARY AND BENEFITS

In summary, the mobile fluidic tank waste retrieval system provides the following benefits:

- Proven technology with a record of accomplishment in safe, successful and efficient operation in the field.
- Promotes and maintains ALARA principles for worker radiological exposure.
- Site operators can be quickly and comprehensively trained to operate the equipment.
- Mobile, modular equipment easily deployed and readily relocated for use on further tank waste retrieval applications.
- The system can mix tank contents to obtain a homogeneous sample of the tank contents and establish confidence regarding the nature of the waste form and tank contents to assist in regulatory compliance.
- Systems can be remotely operated a safe distance away from the radiological/hazardous area, resulting in low to negligible radiological exposure for workers.
- System geometry and modular construction allows the system to be easily decontaminated for ease of transportation and storage.
- Robust principle of operation reduces the risk of operational disruption due to unexpected waste forms or foreign objects in the tank.
- Assemblies installed in the tank can be supported by bridging structures, eliminating unacceptable loading on aging or degraded structures.
- Retrieval skids can be located a safe distance away from the tank to reduce tank-top loading.
- Secondary waste generation is reduced by minimizing the amount of water required to recover sludge in tanks.
- System is flexible with interchangeable nozzles to meet changing waste characteristics during tank recovery.

Since the 1970s over 400 Power Fluidic pumps and mixer systems have been installed into new process plant built by BNFL or AEA Technology. Over 2000 cumulative years of operation have been logged on the equipment without the need to replace major components.

Power Fluidics has established itself as a cost effective, safe, proven and reliable system for addressing mixing, transfer and D&D of nuclear waste in the world market place. The technology is highly transferable between applications, and provides risk reduction in an approach consistent with ALARA principles.

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